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Milli-watt Radioisotope Power to Enable Small, Long-Term Robotic “Probe” Space Exploration

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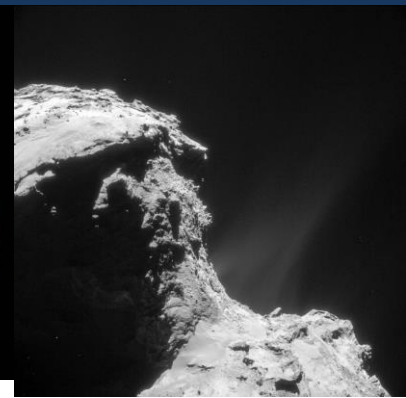
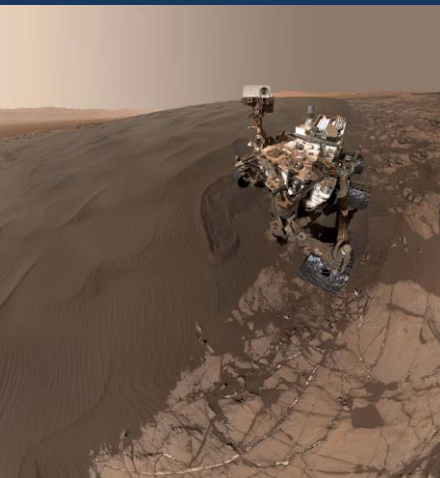
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Introduction/Motivation



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Europa
Image Credit: NASA/JPL-Caltech/SETI Institute

Comet 67P/Churyumov-Gerasimenko
Credit: ESA/Rosetta/NAVCAM

Mars
Credit: NASA/JPL-Caltech/MSSS

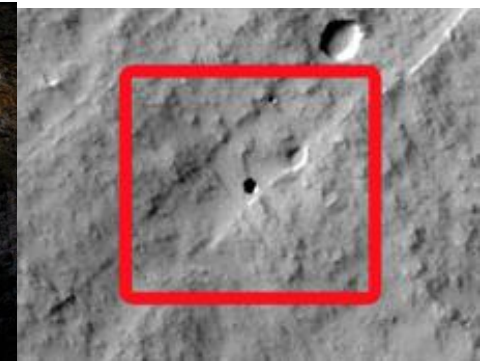
Dusty Solar Panels on Spirit
Image Credit: NASA/JPL-Caltech/Cornell/

Rationale for a Small Radioisotope Thermoelectric Generator (RTG)

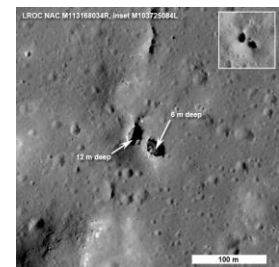
- Efficient use of heat source plutonium and /or stowage volume, low electric and thermal power / energy demand
- Dependable power at large spacecraft to Sun ranges or distances
- Weather conditions / low temperatures on other bodies
- Planetary shadowing / rotational period/ latitude/inclination
- Surface topography features like volcano tubes (possible future human habitats)
- Spacecraft position on the surface (upside down etc.) / spacecraft dimensions / airbag blockage/dust



A caver stands under the skylight in Big Sky Cave.
Credit: www.nps.gov



Lava tubes, cave Mars
NASA/JPL-Caltech/ASU



Lava tubes, cave Moon
Credit: NASA/Goddard/ASU

- RPSs using RHUs could have various modular, compact integrated RHU / thermoelectric (TE) design configurations by combining RHUs with Bi_2Te_3 TE converters.
 - 40, 80 or 120 mW power levels
- These modular, compact and low mass power sources are ideal for enabling a variety of future mission concepts with great potential science return.
 - Small spacecraft
 - Landed robots or robotic packages
 - CubeSats and large number of small spacecraft
 - Impactors
 - Micro landers & rovers
- Waste heat from the cold side or outboard end of the TE converter could also be directed toward electronics and/or batteries to keep them within a suitable temperature range.
- Power can be generated for more than 30 years using the baseline Pu-238 (87.7 year half-life) isotope.
- RPSs using RHUs could satisfy spacecraft electrical and thermal requirements for missions with minimal:
 - Power demand
 - Heat source plutonium inventory
 - Stowage volume

System Concept Description

RHU / TE Concept 40 mW



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- Low-g (<1,000 g's) RHU / TE system concept design.
- Multilayer insulation thermally isolates the Fuel Capsule Holder (FCH).
- Titanium wires provide structural support.
- Both the p- and n-leg thermoelectric materials would be fabricated from Bi_2Te_3 . The LWRHU is contained within the FCH.
- The hot and cold side temperatures are at approximately 200 and 0°C, respectively.
- Internal outgassing may be controlled with cover gasses or vacuum with getters.
- Total mass 760 grams, height 13 cm and diameter 12 cm.
- 1 Bi_2Te_3 thermoelectric couples.
- 1 RHU is contained within the FCH.

Component Name	Component Mass (grams)		
	40 mW	80 mW	120 mW
Module Compression Assembly	15	30	45
RHU	40	80	120
Fuel Capsule Holder	28	45	77
Rigid Frame	0	0	0
Base Top	189	189	230
Base Bottom	189	189	230
Cylinder Wall	121	150	300
Aerogel, Polyimide	178	240	350
Total mass (grams)	760	923	1352
Height (cm)	13	16	12
Diameter (cm)	12	12	13

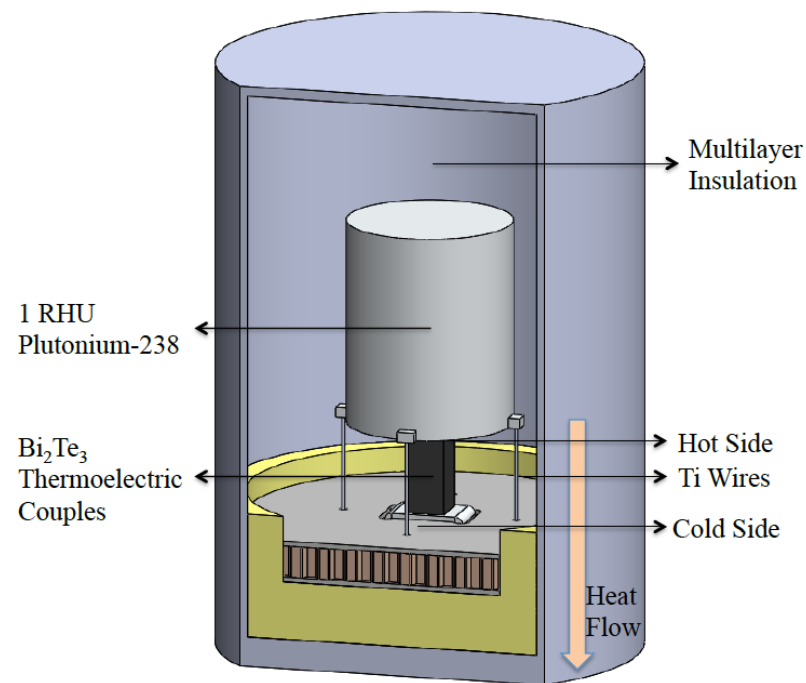


Figure 1. RHU / TE Concept Latest Design (<1,000 g's)
Configurations for Small Robotics and CubeSats
(40 mW)

Table 1. Latest Estimate System Power & Mass Budgets for Envisioned
RHU / TE System Design Configurations (<1,000 g's)

System Concept Description

RHU / TE Concept 80 mW



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- 2 Bi_2Te_3 thermoelectric couples.
- 2 RHUs would be contained within the FCH.
- The hot and cold side temperatures are at approximately 200 and 0°C, respectively.
- Internal outgassing maybe controlled with cover gasses or vacuum with getters.
- Total mass 923 grams, height 16 cm and diameter 12 cm.
- Multilayer insulation thermally isolates the Fuel Capsule Holder (FCH).
- Titanium wires provide structural support.

Component Name	Component Mass (grams)		
	40 mW	80 mW	120 mW
Module Compression Assembly	15	30	45
RHU	40	80	120
Fuel Capsule Holder	28	45	77
Rigid Frame	0	0	0
Base Top	189	189	230
Base Bottom	189	189	230
Cylinder Wall	121	150	300
Aerogel, Polyimide	178	240	350
Total mass (grams)	760	923	1352
Height (cm)	13	16	12
Diameter (cm)	12	12	13

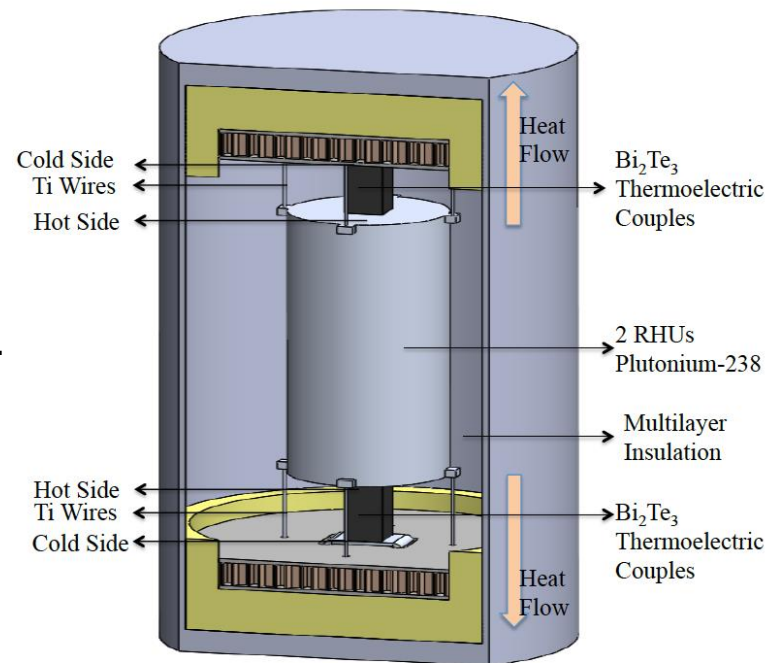


Figure 2. RHU / TE Concept Latest Design (<1,000 g's)
Configurations for Small Robotics and CubeSats
(80 mW)

Table 1. Latest Estimate System Power & Mass Budgets for Envisioned
RHU / TE System Design Configurations (<1,000 g's)

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System Concept Description

RHU / TE Concept 120 mW



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- 3 Bi_2Te_3 thermoelectric couples.
- 3 RHUs would be contained within the FCH.
- Internal outgassing maybe controlled with cover gasses or vacuum with getters.
- Total mass 1.352 Kg, height 12 cm and diameter 13 cm.

Component Name	Component Mass (grams)		
	40 mW	80 mW	120 mW
Module Compression Assembly	15	30	45
RHU	40	80	120
Fuel Capsule Holder	28	45	77
Rigid Frame	0	0	0
Base Top	189	189	230
Base Bottom	189	189	230
Cylinder Wall	121	150	300
Aerogel, Polyimide	178	240	350
Total mass (grams)	760	923	1352
Height (cm)	13	16	12
Diameter (cm)	12	12	13

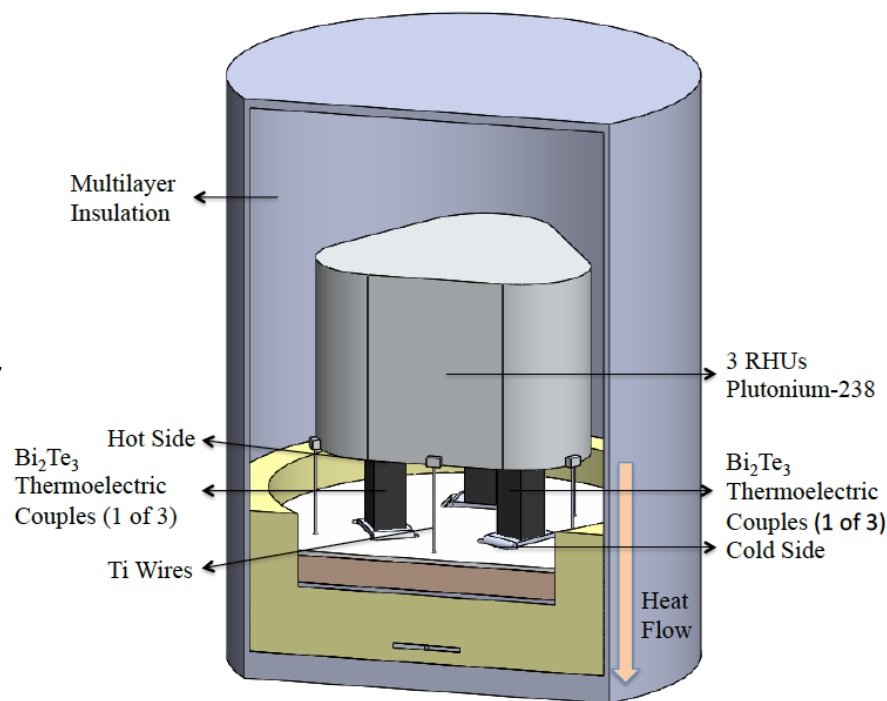


Figure 3. RHU / TE Concept Latest Design (<1,000 g's)
Configurations for Small Robotics and CubeSats
(120 mW)

Table 1. Latest Estimate System Power & Mass Budgets for Envisioned
RHU / TE System Design Configurations (<1,000 g's)

System Concept Description

RHU / TE Concept 40 mW ~10,000 g's



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- The system concept in Figure 4 is probably best suited for impactors or penetrators on various planetary bodies.
- This high impact (~10,000 g's) resistant design would require the longest lead time to develop than all the other (<1,000 g's) designs.
- 1 Bi₂Te₃ thermoelectric couples.
- 1 RHU is contained within the FCH.
- Internal outgassing may be controlled with cover gasses or vacuum with getters.
- Total mass 0.887 Kg, height 17 cm and diameter 12 cm.

Component Name	Component Mass (grams)		
	40 mW	80 mW	120 mW
Module Compression Assembly	15	30	45
RHU	40	80	120
Fuel Capsule Holder	35	52	87
Rigid Frame	120	240	350
Base Top	189	189	230
Base Bottom	189	189	230
Cylinder Wall	121	150	300
Aerogel, Polyimide	178	240	350

Total mass (grams)	887	1170	1712
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Height (cm)	17	17	17
Diameter (cm)	12	15	17

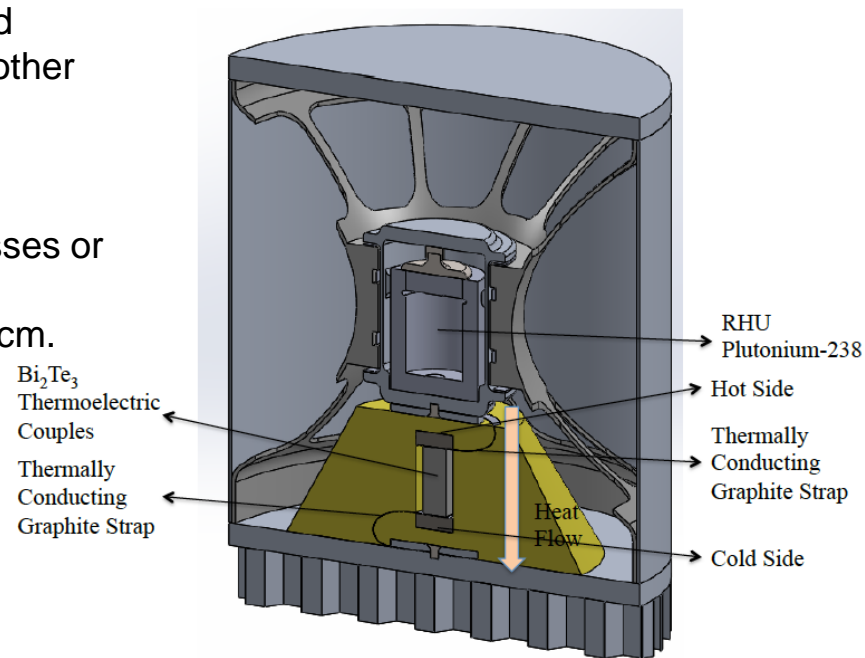


Figure 4. Baseline SBIR Concept Latest Design for ~10,000 g's

Table 2. Latest Estimate System Power & Mass Budgets for Envisioned RHU / TE System Concept Design Configurations (~10,000 g's)

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System Concept Tradeoffs



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	40 mW	80 mW	120 mW
Power/kg [mW/kg]	52.6247	86.6551	88.7377
Power/Volume [mW/cm ³]	0.0272	0.0442	0.0753

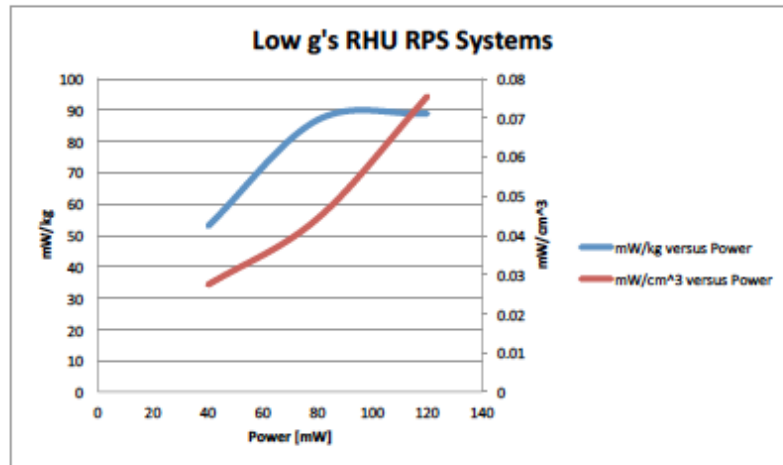


Table 3. Latest Estimate Power-Mass, Power-Volume Impact Level System Tradeoffs for Low g's RHU RPS System concepts

	40 mW	80 mW	120 mW
Power/kg [mW/kg]	45.0958	68.3761	70.0935
Power/Volume [mW/cm ³]	0.0208	0.0266	0.0311

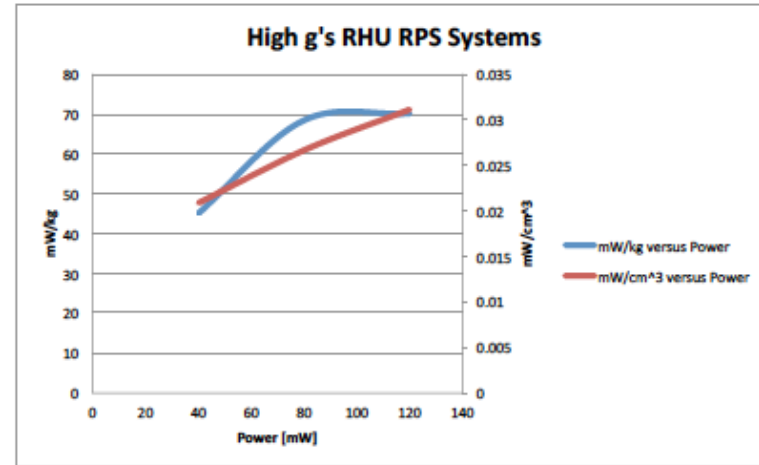


Table 4. Latest Estimate Power-Mass, Power-Volume Impact Level System Tradeoffs for High g's RHU RPS System concepts

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Potential Applications

Two Wheeled Robotic Design Concept



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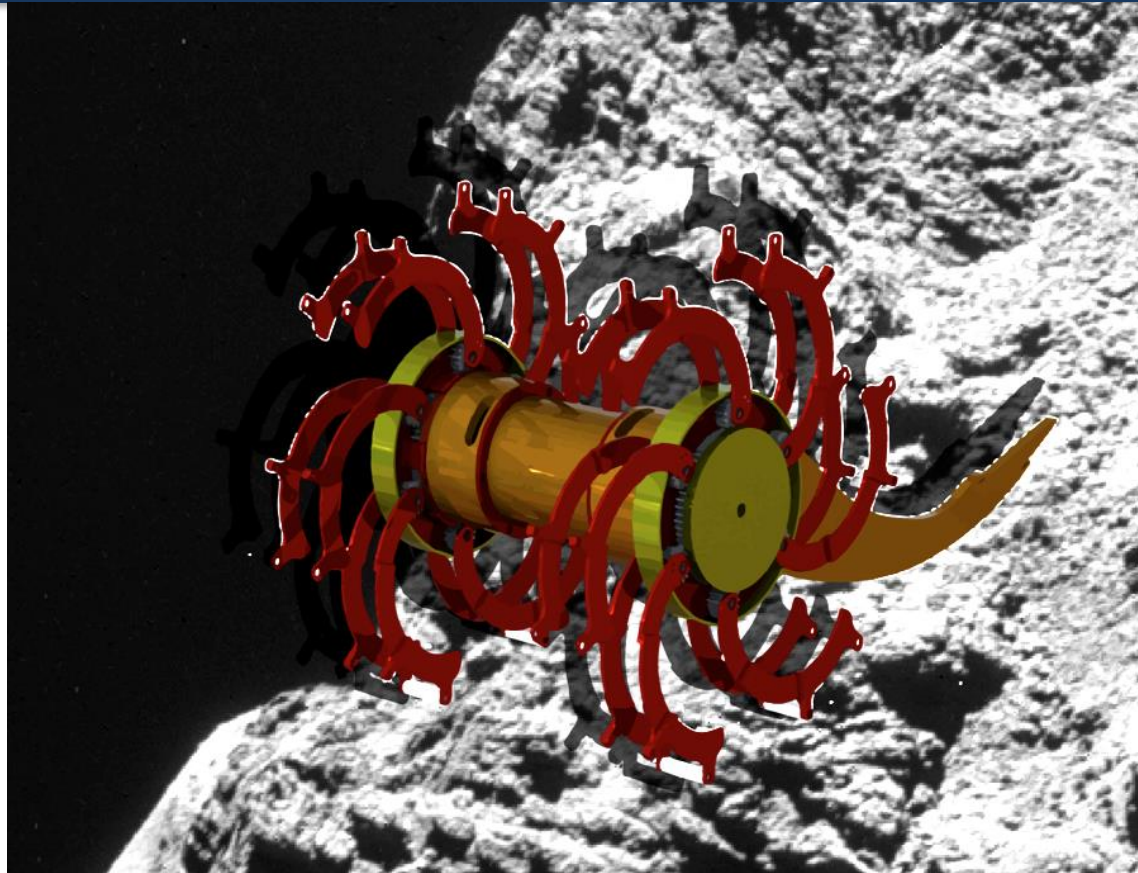


Figure 5. Artist's concept of a two wheeled design with variable radius wheels

- A simple two wheeled robotic design with variable radius wheels
 - Wheels stow in a compact volume
 - Could be actuated into a variety of configurations to overcome mobility challenges
 - Would be well suited to incorporate an RHU/TE RPS.

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Potential Applications

Two Wheeled Robotic Design Concept



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- The RPS could be mounted in the middle of the axle to charge the batteries and/or the supercapacitors.
- Collocating the RPS (waste heat) with the other components inside the insulation package should provide thermal control for:
 - Batteries/Supercapacitors
 - Motors
 - Electronics
- The batteries or supercapacitors, mounted inside the insulation, would slowly charge allowing for approximately four hours of operation or data transmission each day.
- Enable the exploration of:
 - Asteroids
 - The mapping of lava tubes
 - The traversing down of chasms or vents
 - The scouting of cryo-worlds.



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Figure 6. Artist's concept of a two wheeled design with variable radius wheels

- Several recent small robotic missions concepts expressed interest in the mW power technology for Mars, Europa and other small bodies mission's concepts such as:
 - Europa Impactor Micro-lander needing an electrical power level of 10 mW to approximately 100 mW and an RTG configuration of 1 to 4 RHUs. These spacecraft would be experiencing g-loads of less than 5000g's.
 - Titan Micro-Rover needing an electrical power level of 10 mW to approximately 100 mW and an RTG configuration of 1 to 4 RHUs. The spacecraft would experience g-loads from 40 to 600g's.
 - Lunar Micro-Rover, a Mars Micro-Rover and a Pascal Micro-lander for a Mars mission.
 - Mars Deployable Micro-Payload Concept requiring 1 to 2 RHUs configurations for an electrical power of 27 to 40 mW for a spacecraft g-load of less than 40g's.

Other types of possible mission concepts of interest include:

- The Mars Deployable Micro-Seismic Station and the Mars Science Micro-Instrument.
 - The electrical power respectively are 10 to approximately 100 mW and 5 to 50 mW
 - 1 to 4 RHUs for the first mission and 1 to 2 for the second.
 - The specific g load for both missions would be less than 40g's.
- The Europa Impactor Micro-Lander, the Mars Science Microinstrument and the Mars Deployable Micro-Payload concepts discussed previously would all be mission piggybacks onboard other missions
 - Would make them more economically feasible.



Thank You Questions

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